

# CLOSING THOUGHTS

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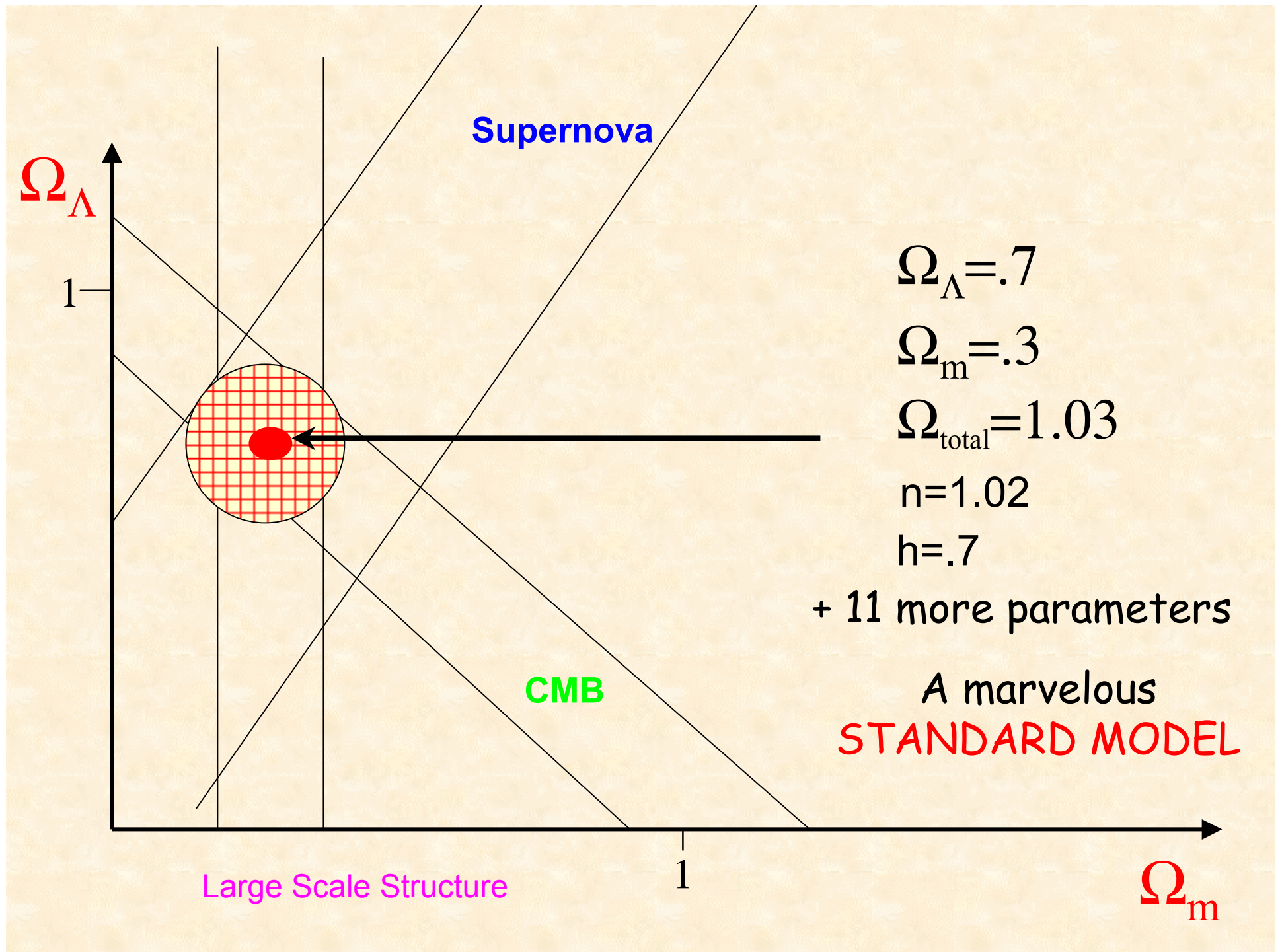
THANKS *Evalyn, John and Sean* FOR A  
CLASSY CONFERENCE

# ENVY

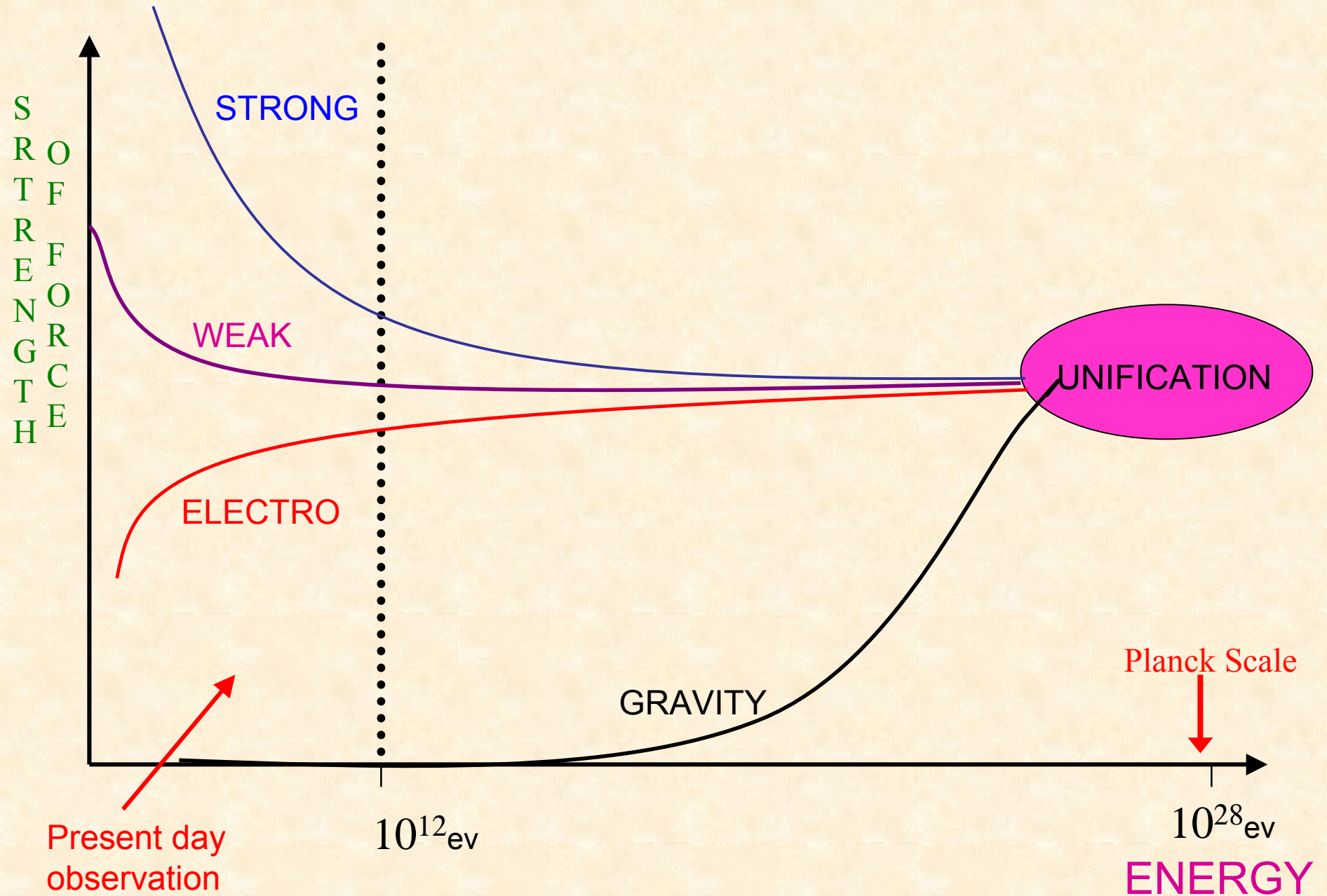
This is truly a golden age of cosmology

Beautiful observations

The emergence of a “standard model”



# THE STANDARD MODEL





# STRONG COUPLING

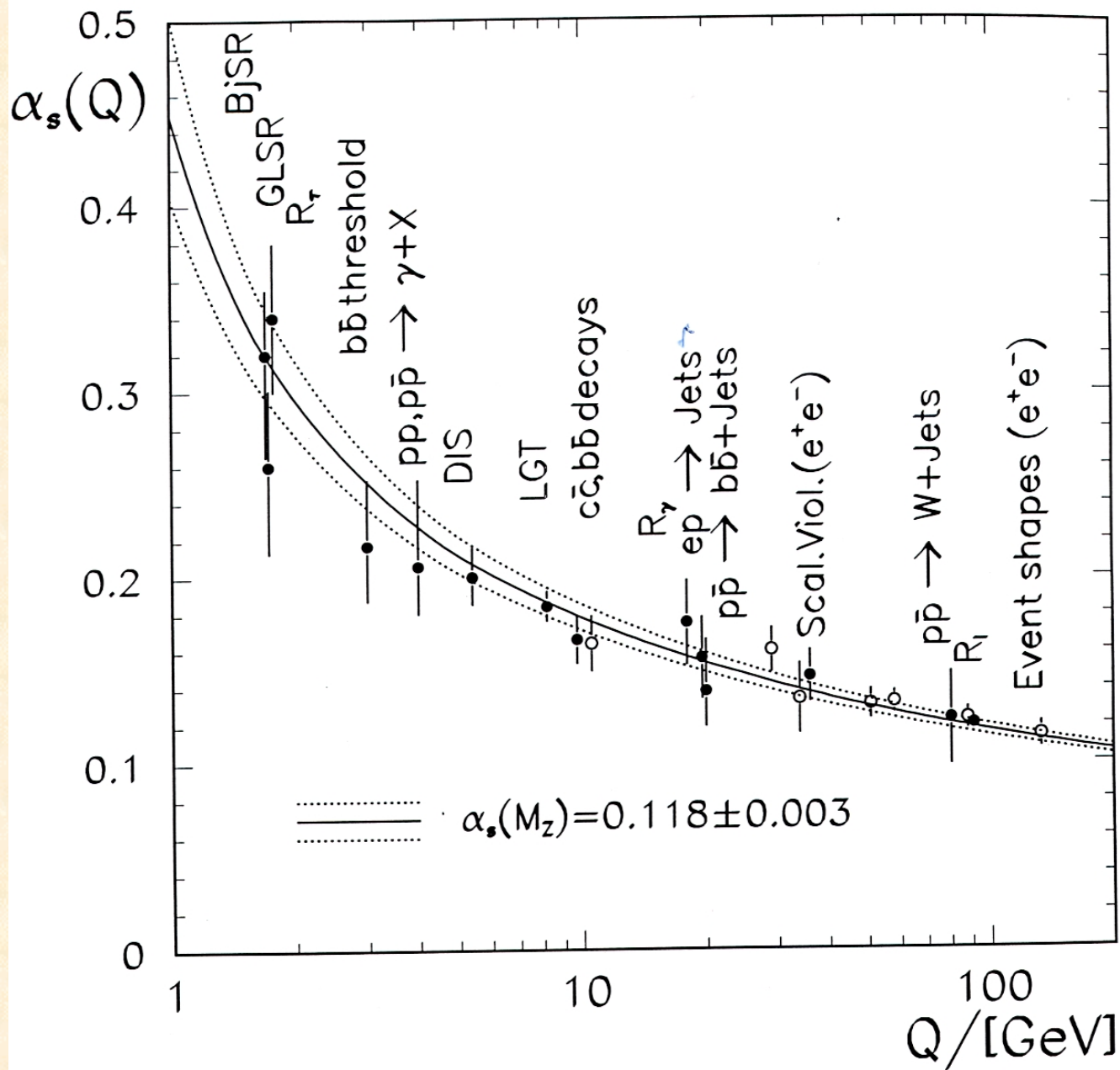
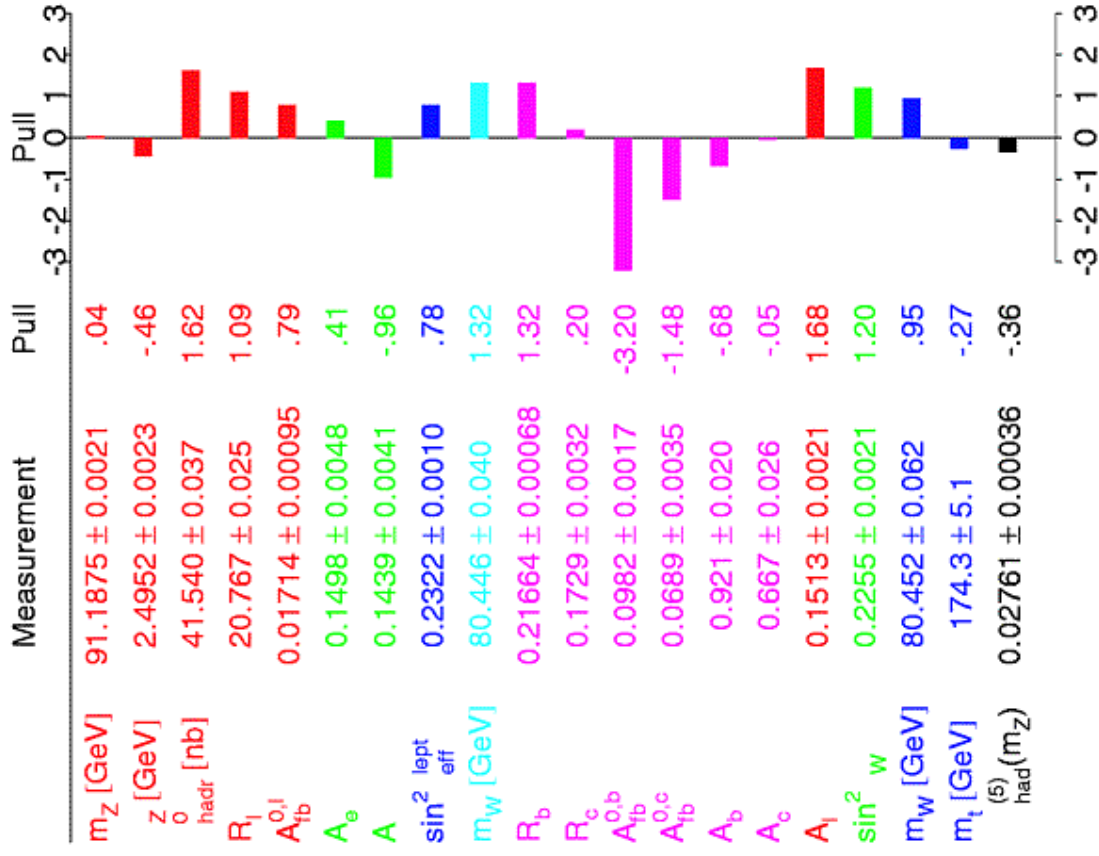
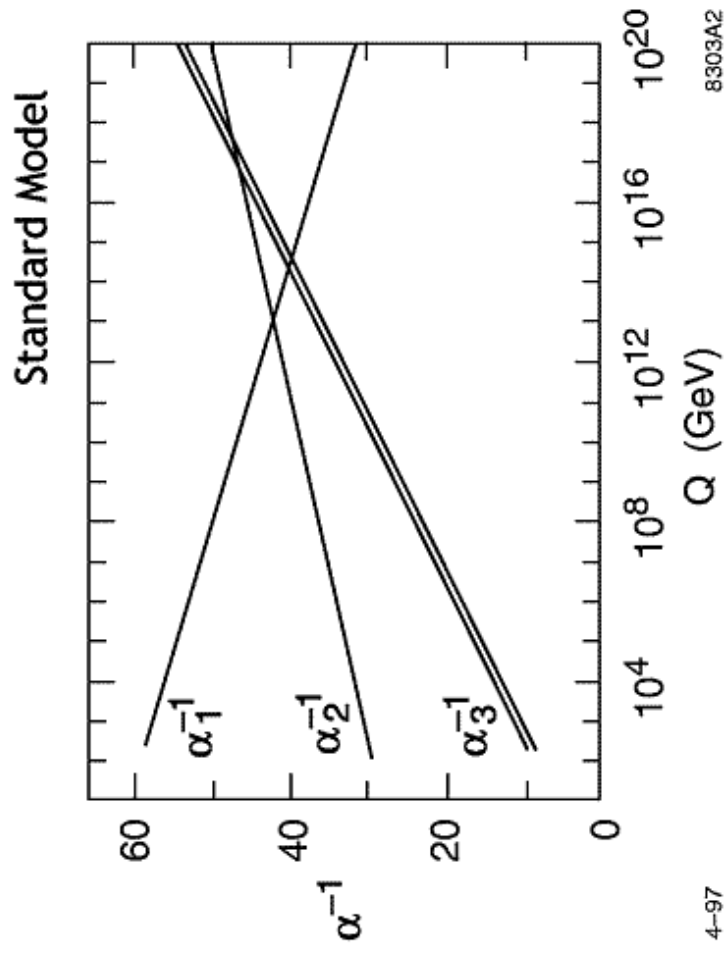


Figure 6: Running of the strong coupling constant established by various types of measurements at different scales, compared to the QCD prediction for  $\alpha_s(M_Z) = 0.118 \pm 0.003$ . The open dots are results based on global event shape variables.

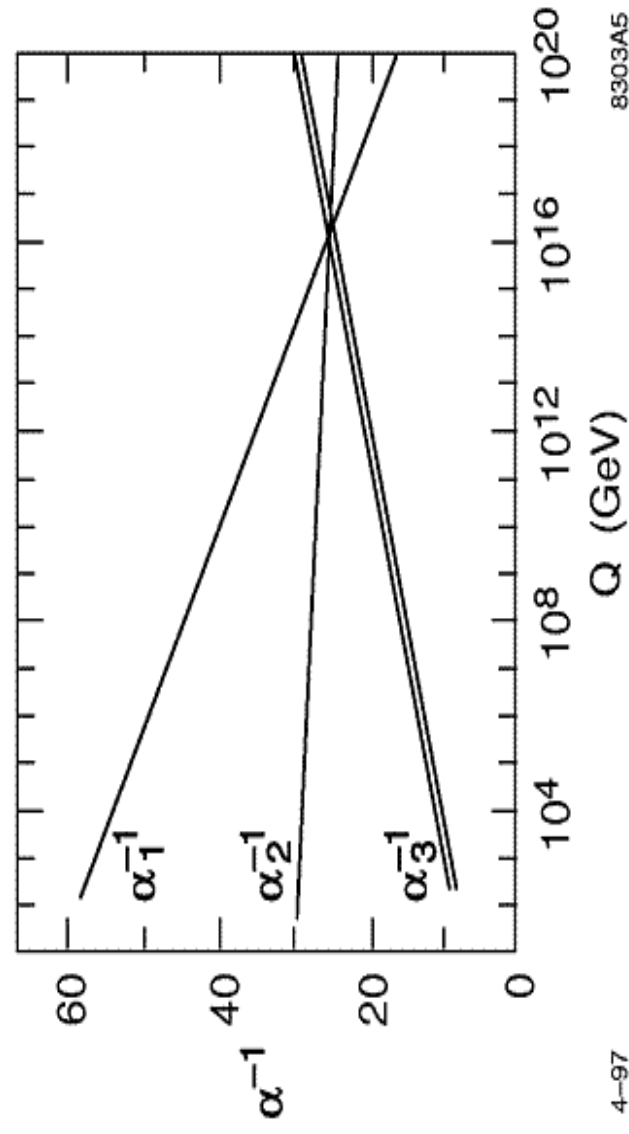
## Winter 2001



LEP Electroweak Working Group

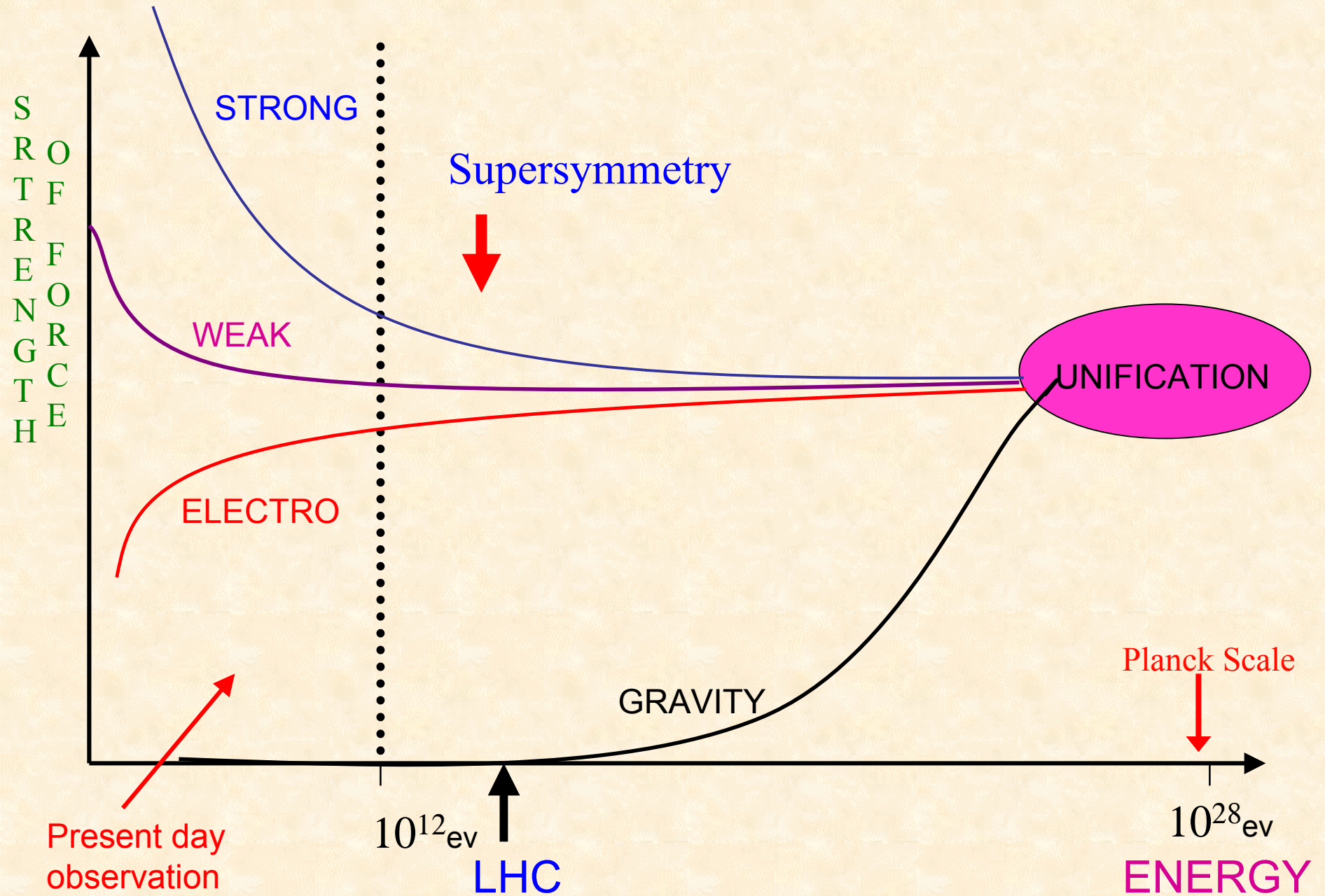


# Standard Model with superpartners





# THE STANDARD MODEL



Astrophysics is a major consumer of theory

As an observational (non-laboratory) science  
Astrophysics requires good theoretical understanding  
in order to interpret observation

Astrophysics is a major consumer of fundamental physics

Quantum Mechanics	spectroscopy, stellar structure ...
General Relativity	cosmic expansion,....
Nuclear Physics	stellar structure, nucleosynthesis,...
Particle Physics	baryogenesis, inflation,...

Has Astrophysical observation discovered new fundamental physics ?

The measurement of planetary motion (Kepler)



Newton's Theory of Gravity

More recently?

Testing ground for fundamental physics

General Relativity, Nuclear fusion, Neutrino physics

Standard Model, Constraints on new physics



Has Astrophysical observation discovered new fundamental physics ?

The measurement of planetary motion (Kepler)



Newton's Theory of Gravity

More recently?

Dark Matter

Many plausible particle  
Physics candidates

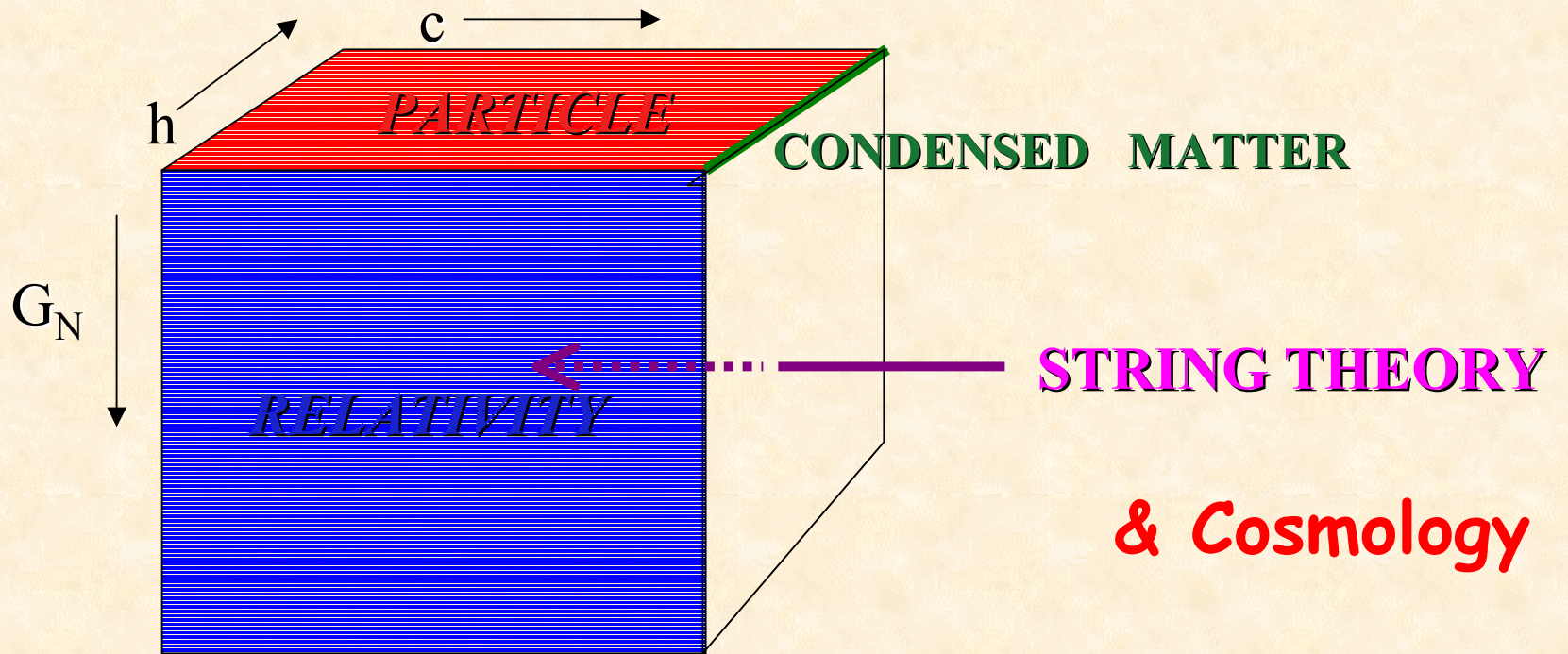
Dark Energy

$\Lambda$

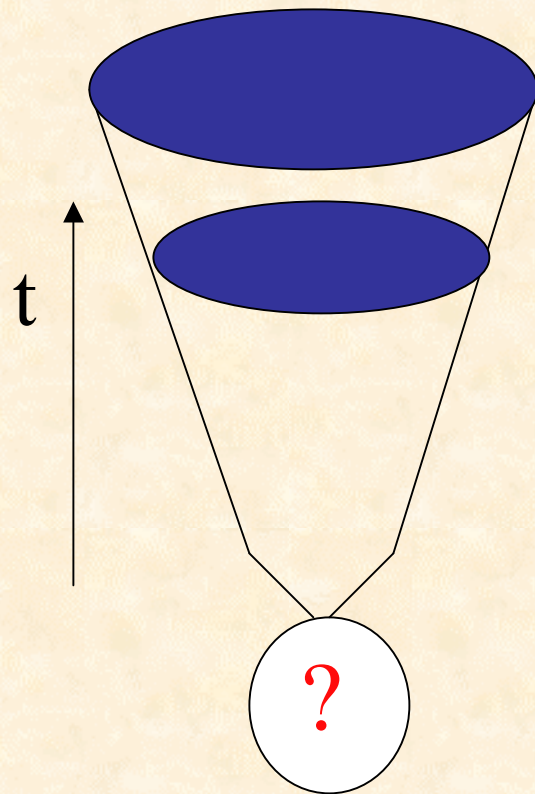
?????



# Theory Space



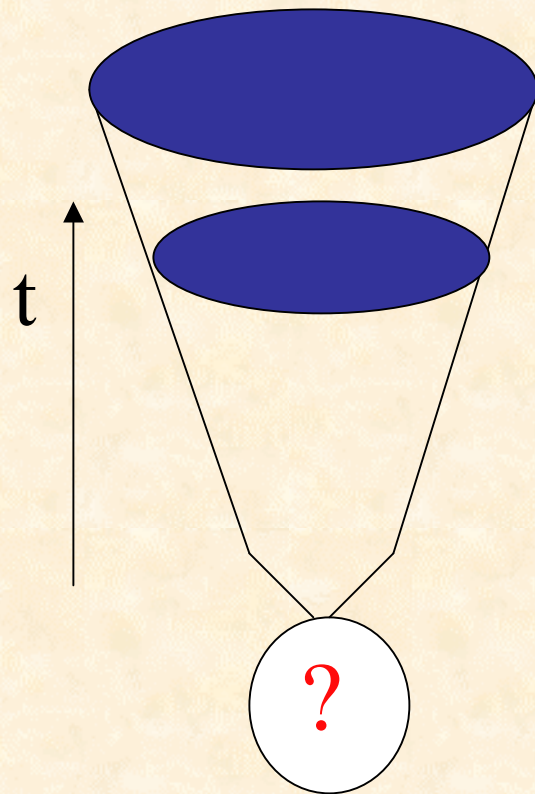
**WILL STRING THEORY YIELD THE PRINCIPLE THAT  
DETERMINES THE HISTORY OF THE UNIVERSE?**



**TIME BEGINS**

Fix uniquely the initial  
condition, the wave  
function of the universe  
at  $t=0$

**WILL STRING THEORY YIELD THE PRINCIPLE THAT  
DETERMINES THE HISTORY OF THE UNIVERSE?**

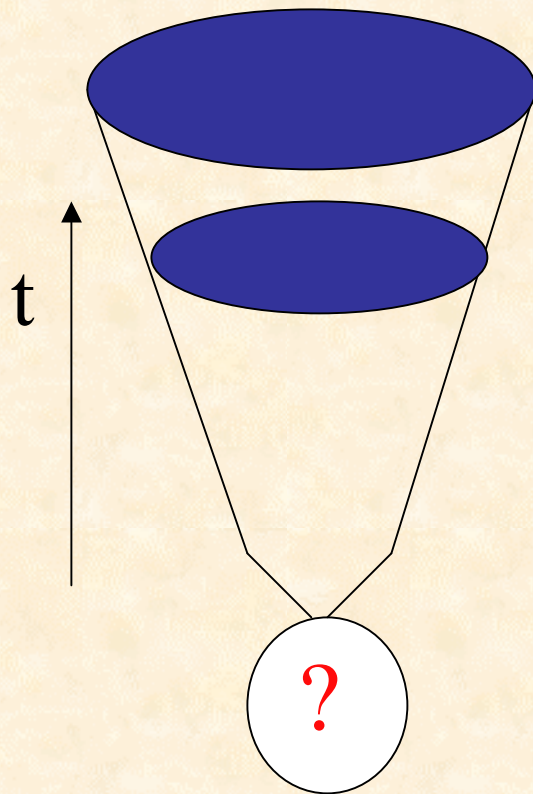


**TIME GOES BACK  
FOREVER**

Cyclic or bouncing universe  
that passes smoothly  
through a "singularity" at  
 $t=0$



**WILL STRING THEORY YIELD THE PRINCIPLE THAT  
DETERMINES THE HISTORY OF THE UNIVERSE?**



**AT THE BEGINNING  
TIME HAS NO MEANING**  
Time is an emergent  
concept



# SPACE-TIME IS DOOMED ?

## IN STRING THEORY WE CAN

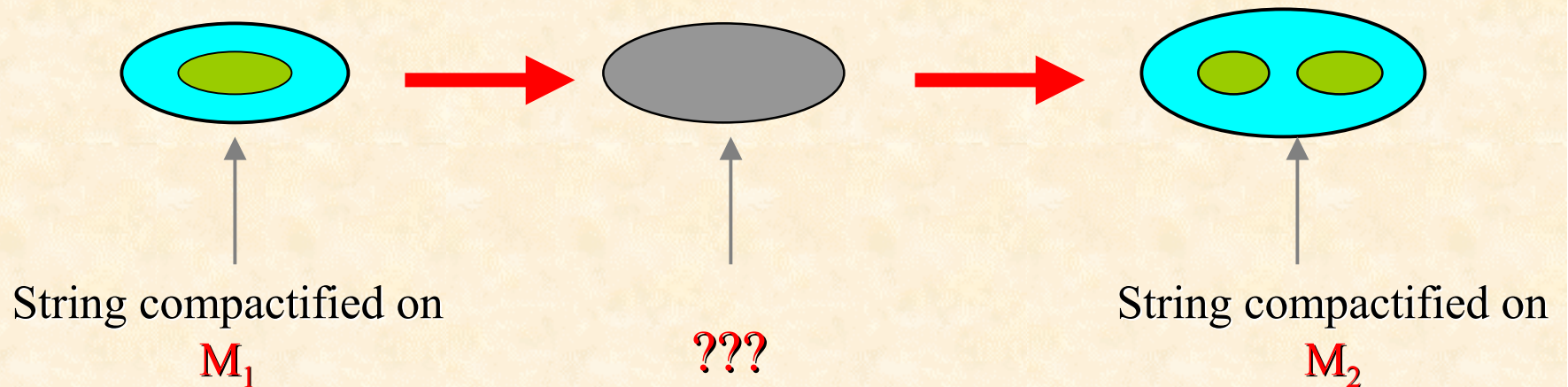
- CHANGE THE NUMBER OF SPATIAL DIMENSIONS

$II_A$  Theory in 10-d  $\longrightarrow$  M-theory in 11-d

$\lambda \ll 1$

$\lambda \gg 1$

- CONTINUOUSLY TEAR THE FABRIC OF SPACE



# IN STRING THEORY WE CANNOT

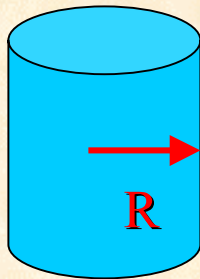
- Probe arbitrarily small distances

## The String Uncertainty Principle

$$\Delta x = \frac{hc}{E} + \frac{GE}{c^4}$$

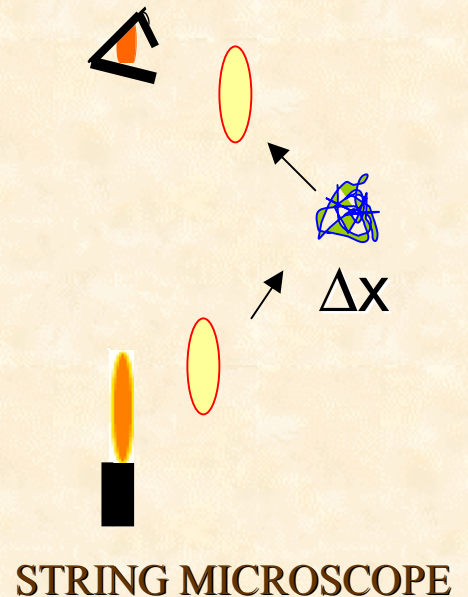
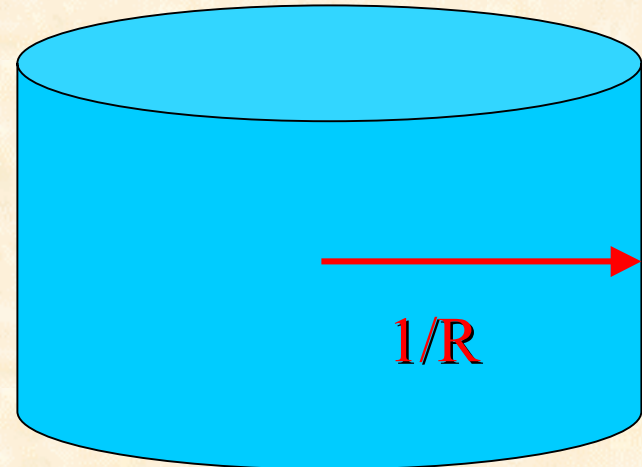
Strings expand  
at high energy

- Squeeze spatial volumes to zero size



=

DUAL TO



WE HAVE HINTS THAT SPACE-TIME CAN BE

**REPLACED**

Space (& time?) are  
emergent concepts



WE HAVE HINTS THAT SPACE-TIME CAN BE

**REPLACED**

e.g. M(atrix) Theory

**HOLOGRAPHICALLY**  
**REPRESENTED**

The fundamental degrees of freedom  
of a consistent theory of **gravity**  
reside on the **boundary** of space time



**WE HAVE HINTS THAT SPACE-TIME CAN BE**

**REPLACED**

e.g. M(atrix) Theory

**HOLOGRAPHICALLY  
REPRESENTED**

e.g. AdS/CFT

**WE HAVE HINTS THAT SPACE-TIME CAN BE**

**REPLACED**

e.g. M(atrix) Theory

**HOLOGRAPHICALLY  
REPRESENTED**

e.g. AdS/CFT

By convention there is color,  
by convention sweetness,  
by convention bitterness,  
but in reality there are atoms and space.

Democritus (400 B.C.)

WE HAVE HINTS THAT SPACE-TIME CAN BE

**REPLACED**

e.g. M(atrix) Theory

**HOLOGRAPHICALLY  
REPRESENTED**

e.g. AdS/CFT

**We are convinced that**

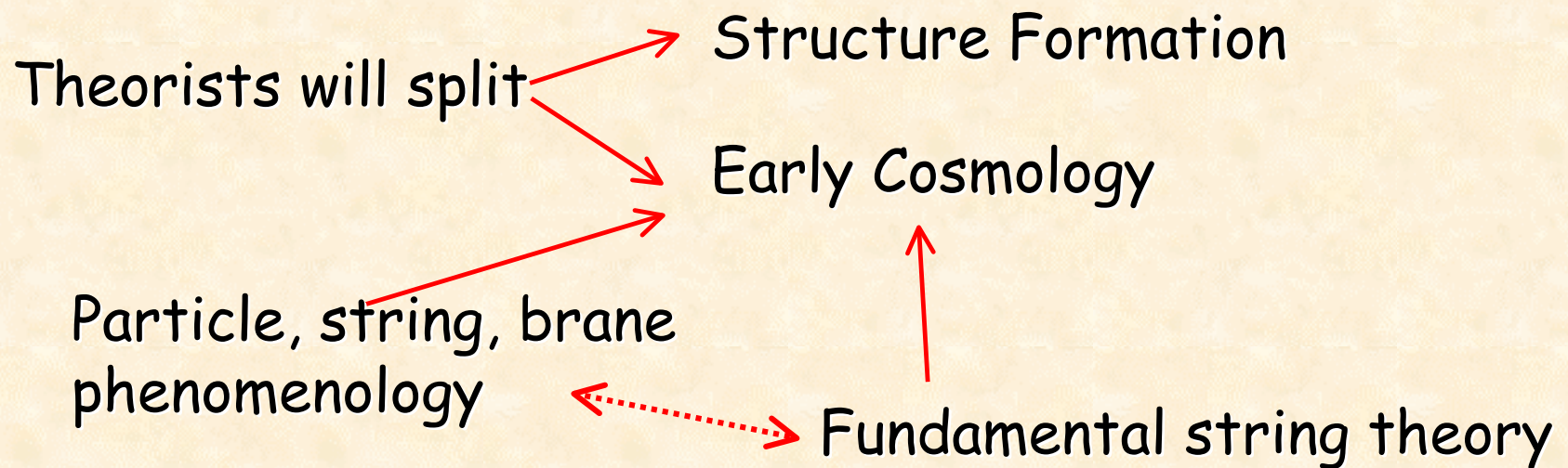
*“by convention there is space,  
by convention there is time,*

*but in reality there is ....”*



# PREDICTIONS

Experimental Cosmology will provide increasingly precise tests of the standard model, Dark matter will be identified





IT SHOULD ALL BE CLEAR  
BY COSMO - 03

THANKS AGAIN FOR A  
CLASSY CONFERENCE

IT SHOULD ALL BE CLEAR  
BY COSMO -2103

THANKS AGAIN FOR A  
CLASSY CONFERENCE